

PA	polyamide
PBT	poly(butylene terephthalate)
PC	polycarbonate
PCTFE	polychlorotrifluoroethylene
PEI	polyetherimide
PEK	polyetherketone
PEN	poly(ethylene-2,6-naphthalene dicarboxylate)
PES	polyethersulfone
PETP	poly(ethylene terephthalate)
PFA	perfluoroalkoxy copolymer
PI	polyimide
PMMA	poly(methyl methacrylate)
PMP	poly(4-methyl-1-pentene)
PP	polypropylene
PPS	poly(phosphorylene sulfide)
PS	polystyrene
PSU	polysulfone
PTFE	polytetrafluoroethylene
PVA	poly(vinyl alcohol)
PVC	poly(vinyl chloride)
PVDC	poly(vinylidene chloride)
PVDF	poly(vinylidene fluoride)
PVF	poly(vinyl fluoride)
TD	transverse

1. Introduction

The term *film* is applied to thin materials present in a continuous planar form, which are at the same time self-supporting and flexible. A film may consist of one or more layers, usually of differing composition. The term generally encompasses both metallic and polymeric substances, which may be either homogeneous or made heterogeneous by the presence of incompatible additives or blending components. In this article, a film is assumed to be a polymeric material which can be wound into a roll. Film thicknesses range from 0.5 μm to ca. 1 mm.

The characteristics of a film are determined primarily by the raw materials employed, but they are additionally affected by processing methods, modification, and converting (e.g., stretching, coating and lamination).

Film materials are of considerable economic importance. In 1986, the annual worldwide consumption of film for packaging and technical applications was ca. 11×10^6 t. Figures for the worldwide consumption of the more important film materials are listed in Table 1.

Films are used as flexible packaging materials, as insulation for electrical conductors, as

Table 1. Worldwide consumption of some of the most important types of film in 1986*

Material	Consumption, 10^6 t
Low-density polyethylene (LDPE)	8.00
Polypropylene, biaxially oriented (BOPP)	0.55
Poly(vinyl chloride) (PVC), rigid and plasticized	1.42
Poly(ethylene terephthalate) (PETP), biaxially oriented	0.55
Cellophane	0.26

* Hoechst marketing research, Kalle Works, Federal Republic of Germany.

protective layers on sensitive surfaces, and as windable base materials for subsequent application of magnetic coatings, electrically conducting, and light-sensitive layers as well as printing inks. Multitudes of film and sheet types have been developed to meet the increasing demands of these applications. These products provide a broad spectrum of mechanical, optical, and electrical properties, as well as various degrees of permeability and stability to temperature and aggressive media.

Historical Aspects [1]. Polymeric films were first developed at the end of the 19th century, when cellulose nitrate was introduced as a base material for photographic emulsions. Other cellulose-based films followed, the most important of which were derived from cellulose acetate and cellulose hydrate. Cellulose triacetate films quickly replaced the highly flammable cellulose nitrate films in the photographic industry; cellulose hydrate films (cellophanes) became important packaging materials, maintaining their dominance until polyolefin films were introduced in the 1950s. Cellophane coated with cellulose nitrate or poly(vinylidene chloride) also played a key role in this respect due to its low permeability to water vapor and oxygen, coupled with desirable sealing properties.

All cellulose-based films are prepared from polymer solutions, however the subsequent introduction of totally synthetic polymers has led to new film production methods, as well as new types of films with unique properties. These developments have been encouraged by the close working relationship between fiber and film producers, particularly in terms of polymer compositions and processing technology.

Important milestones in the development of films included the introduction of

- 1) poly(vinyl chloride) films in the late 1930s
- 2) low-density polyethylene films in the late 1940s
- 3) biaxially oriented polyester and polypropylene films in the 1950s

Parallel and subsequent to these developments, a series of specialty films has emerged. These films are distinguished either by high mechanical or thermal stability, or by special properties such as impermeability to oxygen, advantageous electrical characteristics, or resistance to chemical attack.

2. Production

Generally from both wet and dry processes on two basic types of equipment:

- 1) solution casting
- 2) thermoplastic extrusion

The method chosen depends on the behavior of the material with respect to solvents. In certain cases the behavior is decisive.

For solution casting, the material must first be dissolved in a suitable solvent. The solution is then cast onto a moving support.

Thermoplastic extrusion involves the extrusion of the material into two categories: a) in a roll form from a melt, and b) as a sheet from a melt.

The latter method is particularly important for film production.

2.1. Solution Casting

Solution casting is the most common method for producing films. It involves the dissolution of the polymer in a suitable solvent, followed by casting onto a moving support. The solution is then dried to form the film. This method is suitable for a wide range of polymers and solvents, and can produce films of various thicknesses and properties.

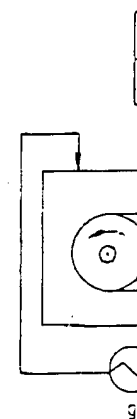


Figure 1. Film production process:
a) Agitator
h) Final dryer

Processing Stabilizers. The thermal decomposition of some film raw materials must be suppressed by addition of processing stabilizers so that the melt can be thermoformed. The choice of stabilizer depends on the decomposition mechanism involved. Thus, sterically hindered phenols effectively stabilize polypropylene, while poly(vinyl chloride) responds to treatment with metal salts (in particular organic tin salts) or *N,N*-diphenylthiourea [102-08-9]. Additive concentrations range from <1 to 3 wt%.

Plasticizers. Plasticizers are particularly useful for adjusting the flexibility of poly(vinyl chloride), cellulose acetate, and cellulose hydrate films. The plasticizer concentration may be as high as 40% (plasticized PVC); typical examples include esters of phthalic and phosphoric acids.

Slip or Antiblocking Agents. Films with smooth surfaces possess a high coefficient of friction and therefore tend to block during winding and other processing operations. To improve the frictional properties of these films, their surface is finely structured by adding small amounts of finely dispersed pigments. The surface of biaxially oriented polyester films can be improved by adding inert inorganic pigments (e.g., calcium carbonate, silicon dioxide, or calcium phosphate) or particles composed of cross-linked polyacrylates. The particles are <1 μm in diameter, and are used at a concentration of <0.5 wt%. Lubricants such as fatty amides or polysiloxanes may also be introduced.

Fillers and Dyes. The optical properties of films can be altered by the incorporation of fillers and dyes. A wide range of concentrations is employed. Many fillers are inert inorganic substances, e.g., titanium dioxide, barium sulfate, kaolin, and carbon black. Colored films are normally produced from raw materials that have been dyed in bulk. However, in special cases the films themselves may be dyed either by a diffusion process or by printing the entire surface.

Antistatic Agents. Films are rendered antistatic by mixing the virgin polymer with a substance bearing hydrophilic groups. The additive migrates to the surface layer. Quaternary ammonium compounds, ethyl sulfonates and, especially with polyolefin films, ethoxylated alkyl amines are used as antistatic agents.

Weathering Stabilizers. Most films for outdoor applications are prone to photooxidative degradation and are stabilized by adding UV-absorbing substances. Piperidyl derivatives, for example, are effective stabilizers of polypropylene.

4. Delivery Forms

Commercial quantities of films are currently available in various thicknesses (ca. 1–1000 μm) and are supplied in the form of rolls with cores of a standard diameter (e.g., 6").

Standardized thicknesses are demanded for many applications. Attempts are being made to establish a standardized system, since this also simplifies production planning and stock control. Films are offered in widths ranging from a few millimeters to several meters. Standard widths have only been established in a few areas of application.

The maximum length of a film depends on the intended application as well as on the film thickness. For example, with poly(ethylene terephthalate) (PETP), films with a thickness of 5 μm are supplied in rolls with a typical length of 30 km.

Films that are precut to size are also marketed, although only to a very limited extent.

5. Test Methods [18]–[24]

Many of the test methods employed for process control in film manufacture have been standardized. However, the results obtained are not always compatible because the test conditions specified in different standards often vary. Therefore, intensive efforts are currently being made to establish international standards.

The chemical composition of a film is normally apparent from its IR spectrum. Trace elements are determined by atomic absorption spectroscopy, mass spectrometry, or neutron activation analysis. Relative molecular masses can be measured from the viscosity of a film solution. The identity of a film can often be determined more simply with the aid of systematic analytical schemes (e.g., [20], Appendix B).

The average thickness of a film is established according to DIN 53 370 or ASTM E 252. No standard method for measuring thickness in both the machine and transverse directions exists as yet. During manufacture, film thickness can

be determined either by β -radiation or by optical methods. The latter is usually carried out on samples cut from the film, or in all cases on the film itself.

Mechanical properties are determined according to DIN 53 370, DIN 53 375, and DIN 53 376. The tensile strength, elongation at break, and modulus are determined.

The compressive strength is determined according to DIN 53 375. The impact strength is determined according to DIN 53 376. The tear strength is determined according to DIN 53 376.

The film is tested according to ASTM D 1708.

The electrical properties are determined according to ASTM D 1708. The dielectric constant, dielectric loss, and volume resistivity are determined.

The thermal properties are determined according to ASTM D 1708. The glass transition temperature, melting point, and thermal stability are determined.

The chemical stability is determined according to ASTM D 1708. The resistance to acids, alkalis, and solvents is determined.

The weathering resistance is determined according to ASTM D 1708. The resistance to UV radiation, moisture, and oxygen is determined.

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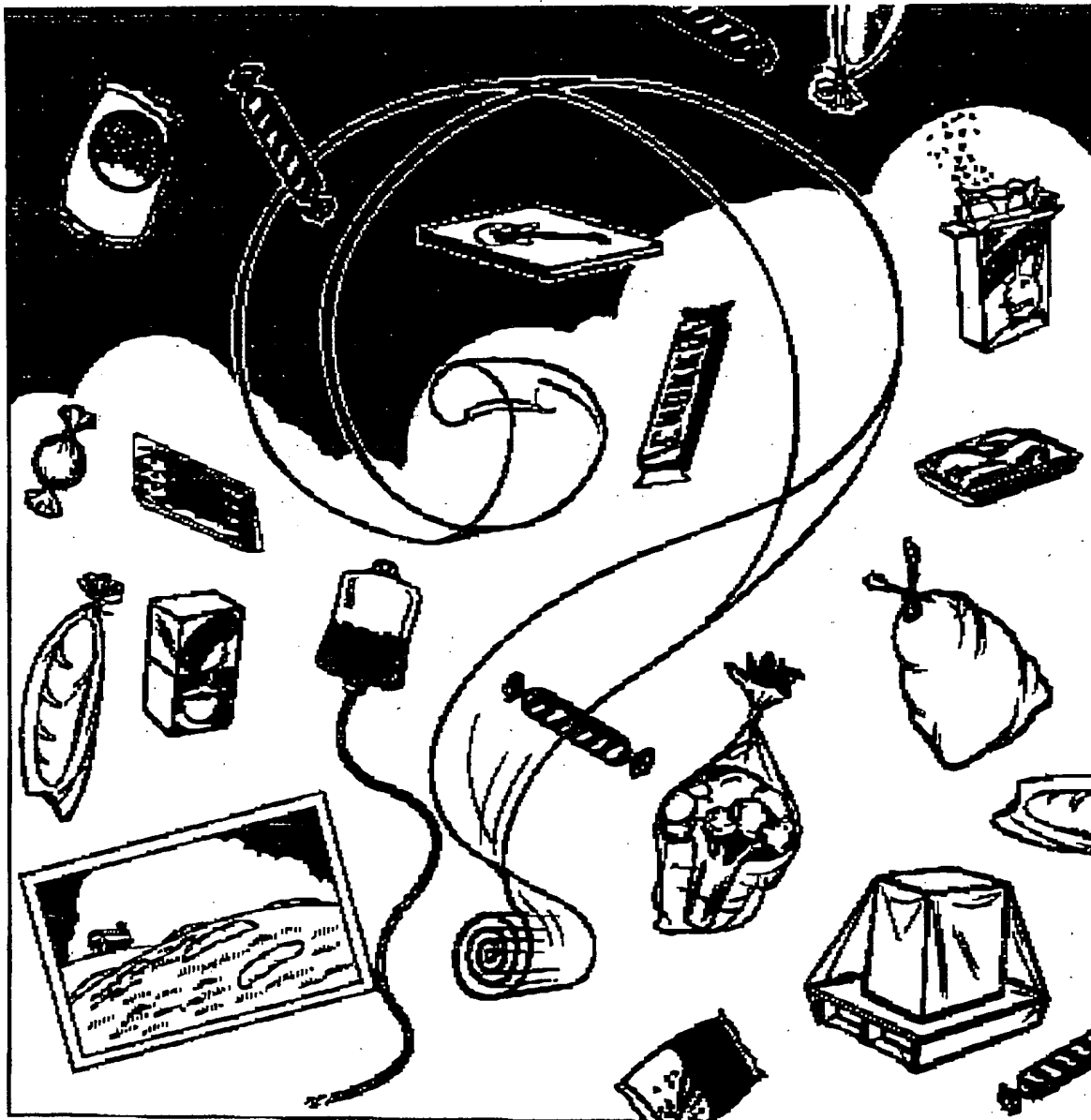
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Its Uses, Benefits and Waste Management Options



American
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WHAT ARE PLASTIC FILMS?

Often when people talk about plastic films—which technically are defined as plastic sold in thicknesses of up to 10 mils¹—they treat them as one type of material, grouping all flexible plastic packaging into a single category. What they do not realize is that plastic films compose a broad category of materials that can be relatively simple or complex depending on the demands of a particular product or package.

Like plastic bottles and containers, film can be made with different resins, each of which has a unique combination of properties that makes it ideal for certain applications. For example, low density polyethylene (LDPE) film acts as a gas barrier, which is necessary

for packaging such things as chicken, which would quickly spoil if exposed to oxygen. Polyvinyl chloride (PVC) film, on the other hand, is gas permeable and necessary for packaging such things as red meat, which require a small amount of oxygen inside the package in order to remain fresh.

Plastic film also can be clear or colored, printed or plain, single- or multilayered and combined with other materials such as aluminum and paper. Thus, the only thing that all plastic film really has in common is that it is flexible in nature, as used in grocery bags, as opposed to rigid, as used in soft drink bottles and butter tubs.

$$10 \text{ mils} = \frac{10}{1000} \text{ inch} = 0.254 \text{ mm} = 254 \text{ } \mu\text{m}$$

HOW MUCH PLASTIC FILM IS THERE?

While it is hard to define plastic film, it is even more difficult to quantify how much of it is used in packaging and nonpackaging applications. That is primarily because of the way that data are reported. For example, trade organizations and major publications rarely separate film from other types of plastic (such as rigid packages), and if they do, the level of detail available on film usage—such as breakdowns by use in food and nonfood packaging—is not consistent across resin types. For that reason, obtaining accurate and complete data on film is a rather arduous task.

Perhaps the best data currently available on film generation are compiled by The Society of the Plastics Industry, Inc. (SPI), which shows that 10,375 million pounds of resin were sold domestically into film applications in 1994 (see Exhibit 1). Interestingly, the polyethylene (PE) family accounts for approximately 86 percent of the resin sold and reported on in that year: Linear low density polyethylene (LLDPE) composed 36.6 percent of the resin sold into film applications. LDPE accounted for 34.8 percent and high density polyethylene (HDPE) accounted for 15 percent. The remaining 14 percent of plastic film was made from polypropylene (PP) at 8.9 percent, PVC at 3.7 percent and nylon at 1 percent.

Even these data, however, are problematic for several reasons. First, figures on film in certain resin categories are reported in combination with other forms of plastic. For example, SPI data include only one

EXHIBIT 1
Resin Sold into Film Applications

Resin	Pounds	Percent
LLDPE	3,801	36.6
LDPE	3,607	34.8
HDPE	1,560	15.0
PP	927	8.9
PVC	387	3.7
Nylon	93	1.0
Total	10,375	100.0

SOURCE: SPI Facts & Figures, 1995

number for both PVC film and sheet. (PVC sheet, which is thicker than PVC film, is semirigid and can be thermoformed into such packages as blister packs, cookie and cracker trays and other types of trays and cartons for food and nonfood applications.) Similarly, the data show only one number for both nylon film and coating.

Second, SPI data do not include information on the amount of polyester (PET) or ethylene vinyl acetate (EVA) sold into film applications, even though they are commonly used to make film. The only data available on these two resins comes from Modern Plastics.

icant savings by not having to haul and dispose of the large quantities of stretch wrap. Therefore, with the money it got from its market plus the money it saved in landfilling minus the cost of collecting and handling, Spartan was actually coming out ahead on its stretch wrap recycling program.

When communities, organizations and/or businesses weigh the pros and cons of recycling plastic film, they must take all of these challenges into consideration.

They must understand film recycling processes and select the one that makes the most sense given the type and quality of potential feedstocks and the end product that will be manufactured. They also must invest in equipment that will enable them to process and upgrade the material so that it is suitable for use in recycled products. And, they must find ways to address the challenges in film recycling by generating a sufficient volume of material, creating an infrastruc-

ADDITIONAL SOURCES OF INFORMATION

In addition to this report, the American Plastics Council currently has three other documents that contain valuable information on film and film recycling: (1) "Plastic Packaging ... Opportunities and Challenges" includes much of the technical information about film packaging found in this report; (2) "Use and Disposal of Plastics in Agriculture," describes and quantifies the amount of film used in agricultural applications and discusses current

recycling activities and (3) "Stretch Wrap Recycling: A How-To Guide," walks through the steps necessary to implement a film collection program in W/DCs and grocery stores. All three of these reports can be ordered through the APC toll-free information line at 1-800-2-HELP-90. In addition, the line has a listing of companies across the country that accept film for recycling.

¹ One mill is equivalent to one one-thousandth of an inch.

² Robert Testin and Peter Vergano, "Plastic Packaging ... Opportunities and Challenges," 1992, pp. 12-13.

³ Testin and Vergano, p. 34.

⁴ Flexible Packaging Association, "The Benefits of Flexible Packaging," p. 3.

⁵ Ibid.

⁶ Data provided by DuPont to the American Plastics Council.

⁷ Testin and Vergano, p. 20.

⁸ Testin and Vergano, p. 37.

⁹ Testin and Vergano, p. 35.

¹⁰ American Plastics Council, "Plastics in Perspective."

¹¹ Testin and Vergano, p. 44.

¹² These data were provided by Ben & Jerry's to the American Plastics Council.

¹³ The Procter and Gamble Company.

¹⁴ Franklin Associates' numbers vary from those cited earlier in the report because Franklin bases its estimates on sales data provided by Modern Plastics, whereas the data reported earlier are provided by The Society of the Plastics Industry, Inc. (SPI), both of which calculate their numbers differently. The Franklin numbers are used at this point in the document because they are the best available data dealing specifically with waste generation. They also show the sectors in which film is generated and how much is landfilled and combusted. Similar data are not available from SPI.

¹⁵ "Characterization of Municipal Solid Waste in the United States: 1995 Update," U.S. Environmental Protection Agency.

¹⁶ The League of Women Voters, "The Plastic Waste Primer: A Handbook for Citizens," p. 103.

¹⁷ Dr. J. Winston Porter, "Plastics and Waste-to-Energy Combustion," The League of Women Voters, "Plastic Waste Primer: A Handbook for Citizens," p. 98.

¹⁸ American Society of Mechanical Engineers, "The Relationship Between Chlorine in Waste Streams and Dioxin Emissions from Waste Combustor Stacks," 1995, CRTD Vol. 36.

¹⁹ Association of Plastics Manufacturers in Europe, "Energy Recovery Through Co-combustion of Mixed Plastics Waste," 1994.

²⁰ D. A. Kahl Consulting, memo on plastic densification technology, 1995.

²¹ Testin and Vergano, pp. 22-24.

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